iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** IV **Month of publication:** April 2017

DOI: http://doi.org/10.22214/ijraset.2017.4236

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Study Paper on Methods of Measurement of Residual Stress in Mechanical Components

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Abstract: ***Now a days study of residual stress is becoming more important as they influences the fatigue behavior and breaking strength of the mechanical component and even its corrosion resistance. The residual stresses can cause extensive dimensional changes, most of the times they are introduce intentionally as they can be beneficial. Therefore it becomes necessary to measure the distribution of residual stresses. Various methods are available for measurement of residual stress. The information regarding residual stresses is already been widely available .This paper aims to advise or suggest the available method for measurement of residual stresses.***
Keywords: residual stress,distructive method, deep hole drilling method, incrimental hole drilling method

I. INTRODUCTION

During manufacturing of Mechanical components various stress are generated. This stress may be desirable or undesirable. Most of the time these stresses are responsible for failure of mechanical components. Hence residual stress analysis is an important stage while designing the mechanical components. During analysis, various methods are available such as destructive (counter method, sectioning technique), semi destructive (hole drilling, deep hole drilling) and non-destructive (x-ray diffraction , neutron diffraction).

II. DEFINATION OF RESIDUAL STRESS

Residual stresses can be define as the stresses that remain in mechanical component during manufacturing process after the original stresses has been removed. They can also be produced by service loading.

III. CAUSE OF RESIDUAL STRESS

Residual stresses are generated during most manufacturing processes involving material deformation, heat treatment, machining or processing operations that transform the shape or change the properties of a material. They are originated from a number of sources and can be present in the mechanical component, introduced during manufacturing or arise from in-service loading.

IV. CLASSIFICATION OF RESIDUAL STRESS MEASURING METHODS

Many techniques exist for the measurement of residual stresses within mechanical components; however it is the effects of the residual stresses that are actually measured not the stresses themselves. The techniques are generally classified into destructive, semi destructive and non-destructive techniques.

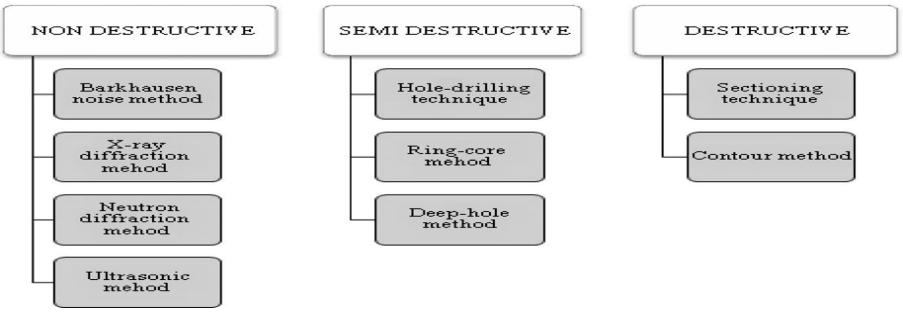

Fig 1.1 Classification of Residual stresses measuring techniques

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A. Destructive Technique

Many techniques exist for the measurement of residual stresses within engineering components; however it is the effects of the residual stresses that are actually measured not the stresses themselves. The destructive techniques are also known as Mechanical Strain Release (MSR) techniques.

Destructive technique includes following methods

1) *Sectioning Technique:* Measurement of residual stresses by the sectioning method has been used for decades to measure residual stresses in structural members. This method has proven itself adequate, accurate and economical if proper care is token in the preparation of the specimen and the procedure of measurement. However, a standard procedure to carry out such measurement does not exist in the published literature. In this paper, o detailed description is presented on the procedure of testing, preparation of specimen, the required tools and measuring devices and working conditions. For a specific cornparision of results, measurements of residual stresses were performed on a specimen having a uniform residual stress distribution along its length..The sectioning method consists in making a cut on an instrumented plate in order to release the residual stresses that were present on the cutting line. For this, the cutting process used should not introduce plasticity or heat, so that the original residual stress can be measured without the influence of plasticity effects on the cutting planes' surface.
2) *Contour Method:* This method measures the residual stress on a 2 plane section through a specimen, in a uniaxial direction normal to a surface cut through the specimen with wire EDM.

At present the technique can readily measure residual stresses across sections greater than 5 mm thick and welded structures where the microstructure varies. It is increasingly being applied to map residual stresses in components to support structural integrity assessments, validate process models including weld simulation and underwrite new manufacturing routes across diverse industry sectors nuclear, power generation, aerospace, petrochemical and transport).

The method involves making a straight cut in the sample of interest along a plane where knowledge of residual stresses is required. The created cut surfaces locally deform owing to the relaxation of residual stresses present before the cut. These deformations are measured and then applied as a boundary condition in a finite element model to determine the out-of-plane residual stress distribution at the cut surface.

B. Semi Destructive Technique

Similarly to the destructive techniques, these also function using the "strain release" principle. However, they remove only a small amount of material, leaving the overall integrity of the structure intact. These include:

1) *Deep Hole Drilling Method:* Deep-hole drilling (DHD) is a technique that allows the measurement of residual stress fields through very thick components. The main assumption of this method is that the drilling of the reference hole has no effect on the residual stress state and that removing the core causes the residual stresses around the hole to be fully released in an elastic manner. The deep hole drilling technique has usually been used on metal parts such as in welds and railway tracks. In metallic components, EDM can be used to trepan a central core around the reference hole since the cutting stresses introduced by this method are not significant. The hole-drilling method involves three major aspects:

   First a reference hole is drilled through the thickness of the specimen using a self-aligning gun drill

   The diameter of the reference hole is measured accurately using an air probe at different angles around the reference hole and at equal intervals through the thickness of the sample

   Then a core coaxial to the reference hole is trepanned using an electro discharge machining in metallic components.

   Finally the reference hole diameter is re-measured at the same angular positions and depth intervals used before trepanning (Fig.1.2d), The distortion of the reference hole.

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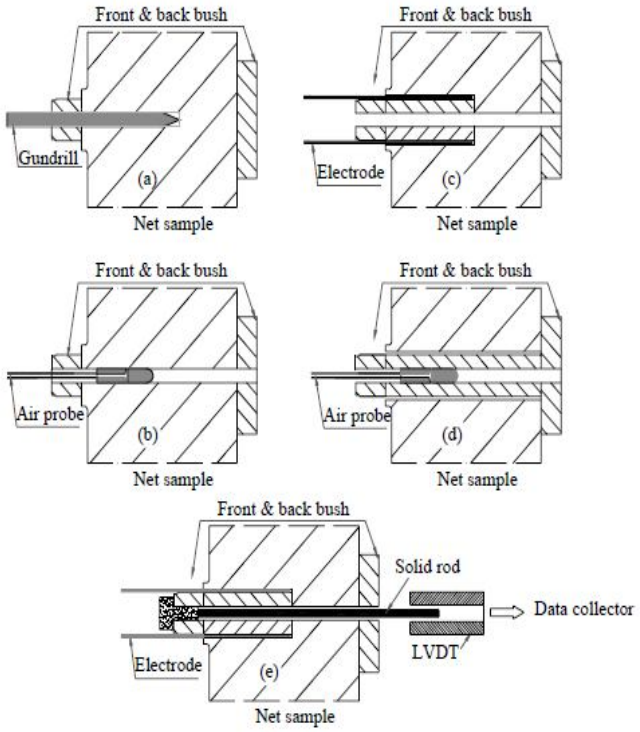

Fig. 1 A schematic diagram illustrating the procedures in the deep hole drilling technique: a) drill reference hole; b) diametral measurement of the reference hole; c) trepanning; re-measure the reference hole; e) axial strain measurement.

2) *Incremental Hole Drilling Method:* The incremental hole-drilling method is a widely used technique to determine residual stress depth profiles in technical components. Its application is limited in respect to the components geometry, for instance the components thickness. In this paper, a direct correction of the measured strain relaxations is proposed to consider the impact of deviant geometries, here the component thickness, on the residual stress evaluation that moreover, allows the application of commercially available evaluation software. The here in proposed approach is based on finite element simulation of the incremental hole drilling. The simulated strain relaxations for thin metal sheets are evaluated with an algorithm as used in commercially available evaluation software (i) for uncorrected data as well as (ii) for strain data corrected by the proposed correction procedure. It is shown that the correction approach leads to a significant improvement of the measurement accuracy. Further, by means of the approach residual stress depth profiles in thin metal sheets can be as usual determined using commercial evaluation software for the incremental hole-drilling method regardless of the algorithm used, i.e. differential or integral.

C. *Non Destructive Technique:* The non-destructive techniques work on the relationship between stress and the physical or crystallographic properties of the component material. The diffraction techniques (a subset of non-destructive techniques) measure variations in the lattice spacing of polycrystalline materials due to stress. The Ultrasound Technique measures variations in speed of ultrasound waves passing through the stressed material and the Magnetic Techniques rely on the interaction between magnetisation and elastic strain in ferromagnetic materials.

1) *Neutron Diffraction:* Neutron Diffraction is a specialized measurement technique used to develop bulk residual stress data in thick sections. The method can be applied to quantify the average residual stress over the measurement gage volume (8 to 125 mm^3 is the typical gage volume). Rotating the specimen in different orientations allows for the measurement of multiple residual stress components and translating the specimen allows for the measurement of multiple points within the body. Many points within the body can be measured in multiple orientations to generate a 2D (or 3D) residual stress map.
Neutron Diffraction residual stress measurements require a neutron source Neutron diffraction is useful for:
Measuring multiple stress components in three dimensions
Mapping residual stresses in large sections

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Parts with large or complex geometry.

Neutron diffraction has some unique characteristics when compared to other types of radiation. This makes it very useful for the study of the atomic structure of liquids, amorphous materials and crystalline materials. Diffraction can see the ordered part of systems, which means, for ordered systems (crystals), their average structure but also deviations from this perfect order; for disordered systems, the ordered portions existing amid this disorder.

2) *X-Ray Diffraction:* The X-ray Diffraction (XRD) technique is the most widely used non-destructive technique, specialising in the measurement of surface residual stresses. Using laboratory-based or portable equipment, the XRD technique measures surface residual stresses to depths of up to 30μm by measuring the material's inter-atomic spacing. The X-ray method is a non-destructive technique for the measurement of residual stresses on the surface of materials. X-ray diffraction techniques exploit the fact that when a metal is under stress, applied or residual stress, the resulting elastic strains cause the atomic planes in the metallic crystal structure to change their spacings. X-ray diffraction can directly measure this inter-planar atomic spacing; from this quantity, the total stress on the metal can then be obtained.

3) *Ultrasonic Method:* Ultrasonic waves (2 MHz - 10 MHz) are commonly used to detect flaws in engineering materials; however they can also be used for the measurement of stresses, applied and residual. The speed of ultrasonic waves travelling through a material are affected by the direction and magnitude of the stresses present, which is called the acoustoelastic effect. Therefore the magnitude and direction of the stresses present within a material can be calculated by accurately measuring the change in time-of-flight of an ultrasonic wave traveling through the stressed and unstressed regions of that material. For example, a stress of 1MPa in aluminium corresponds to a change in time-of-flight of roughly 1.7 ns. The acoustoelastic effect is most sensitive when the propagation path and particle motion of the ultrasonic wave are parallel to the direction of stress being measured. Different configurations of ultrasonic equipment can be used for residual stresses measurements. Overall, waves are launched by a transmitting transducer, propagate through a region of the material, and are detected by a receiving transducer. The technique in which the same transducer is used for excitation and receiving of ultrasonic waves is often called the pulse echo method. This method is effective for the analysis of residual stresses in the interior of the material. In this case the through thickness average of the residual stresses is measured. The depth of this layer is related to the ultrasonic wave-length, often exceeding a few millimetres, and hence is much greater that obtained by X-ray method. Other advantages of the ultrasonic technique are the facts that instrumentation is convenient to use, quick to step up, portable, inexpensive, and free of radiation hazards.

D. Comparison of the Residual Stresses Measurement Techniques

Table 1 Comparison of the residual stresses measurement techniques.

TECNIQUES	ADVANTAGES	DISADVANTAGES
Sectioning method	Wide range of material Economy and speed Hand held	Destructive Interpretation of data Limited strength resolution
Contour method	High resolution maps of stress normal to the cut surface Hand held Wide range of material Larger component	Destructive Interpretation of data Impossible to make successive slices close together
Deep hole drilling method	Deep interior stresses measurement Thick section component Wide range of material	Interpretation of data Semi destructive Limited strain sensitivity and resolution

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Incremental hole drilling	Fast Easy use Generally available Hand held Wide range of material	Interpretation of data Semi destructive Limited strain sensitivity and resolution
Neutron diffraction	Micro and macro RS Optimal penetration and resolution 3D maps	Only Ferro magnetic materials Need to divide the micro structure signal from that due to stress
X-ray diffraction	Ductile Generally available Wide range of material available Hand held system Micro and macro RS	Lab base system Small components Only basic measurement
Ultrasonic method	Generally available Very quick Low cost Hand held	Limited resolution Bulk measurement over whole volume

V. SUMMARY

The paper provide an overview of the different residual stress measurement techniques available and guide the Engineer towards key points of technique for further and more in-depth reading. Also provided the comparison of technique and also the favourable condition in which this techniques can be used. Table advantages and disadvantages of destructive, semi destructive and non destructive methods are listed in this paper. Also we have studied different method available for measurement in destructive, semi destructive and non destructive method. This paper will provide information regarding technique selection and method selection while measuring the residual stress in mechanical component.

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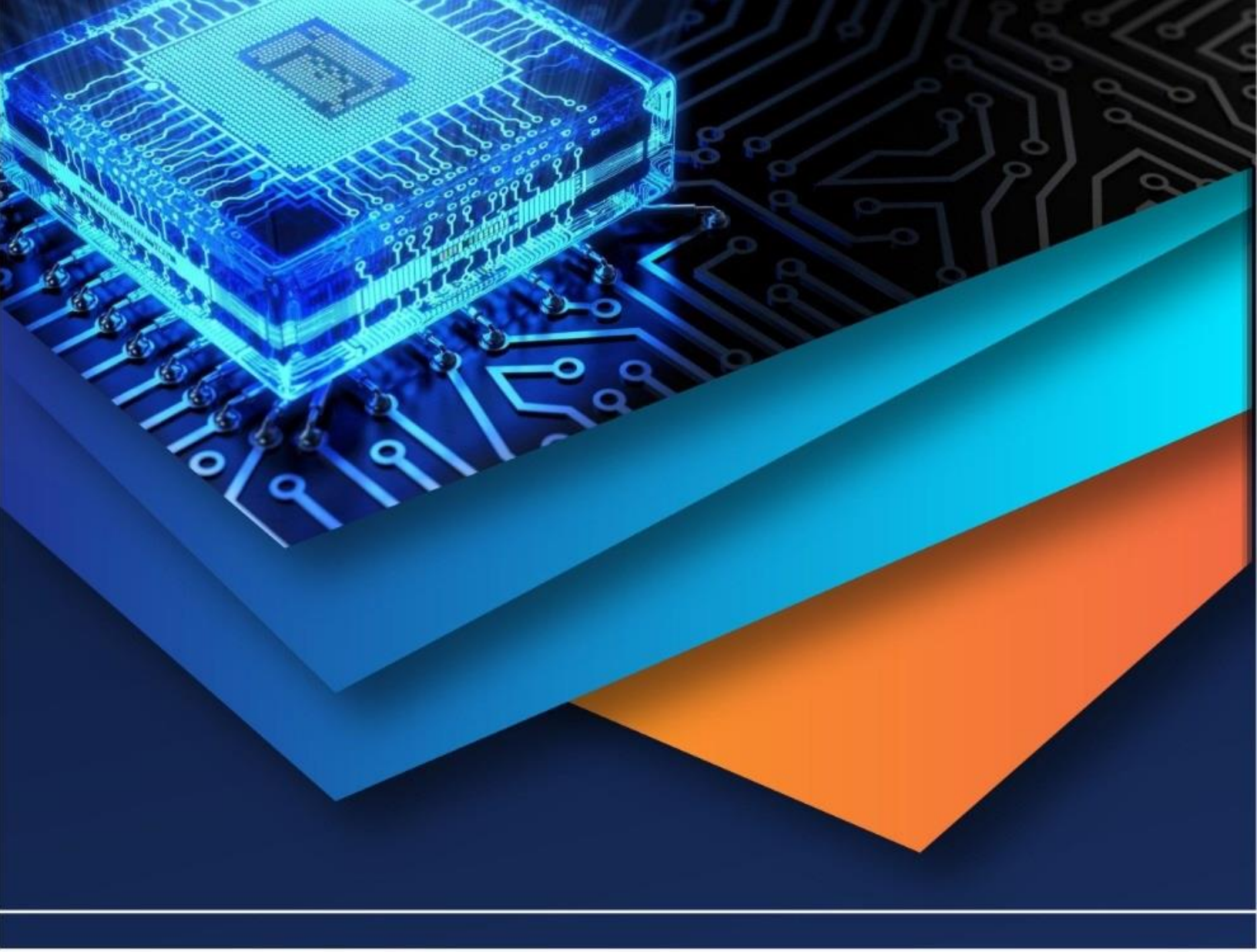

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